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Work function tuning of the individual polyaniline/carbon nanotube nanostructures

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The creation of electronic components on single nanostructures is an important direction in the development of science. Polyaniline (PANI) composites with carbon nanotubes (CNTs) are a promising material for achieving this goal. This is primarily due to the unique properties of the polymer, as well as their improvement when introducing CNTs into its matrix [1]. It is possible to extract single nanotubes coated with a PANI layer, which should have better electrical properties than the bulk PANI/CNT composite. The aim of this work is to study the electronic properties of individual PANI/CNT nanostructures.

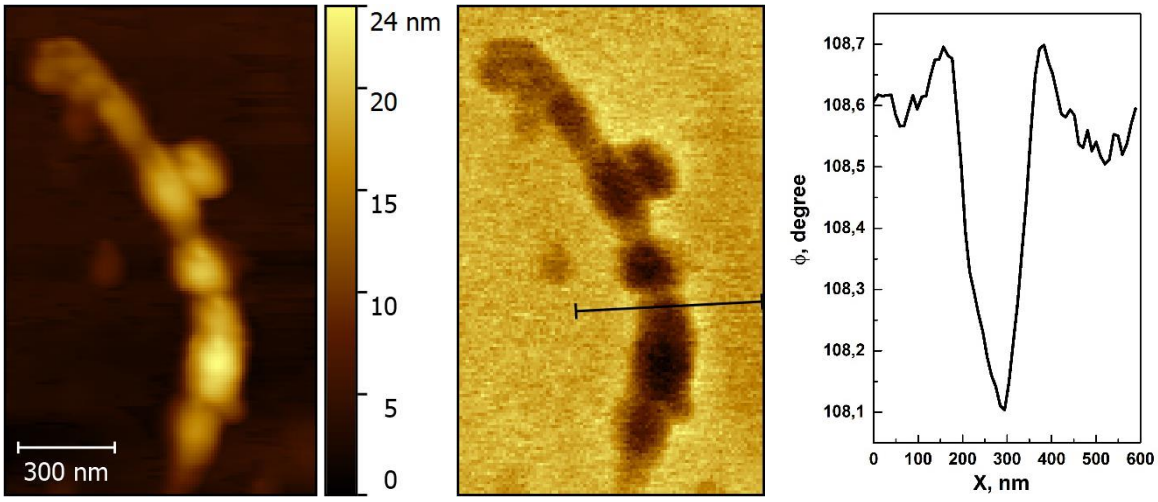
Composite PANI with nitrogen-doped CNT (N-CNT) was obtained via in-situ chemical oxidative polymerization of aniline in the presence of nanotubes. Individual nanostructures of PANI/N-CNTs were separate from the volume of the composite by sonication. The suspension was deposited on a $Si0_2$/Si substrate for study by AFM. Electrostatic force microscopy (EFM) was used to calculate the work function. For comparison, the values of the work function of N-CNT and PANI/N-CNT composite film (thickness 40 nm) were used.

Figure 1 shows an example of the PANI/N-CNT nanostructure morphology, EFM signal, and EFM profile along the line at a tip potential equal to 5V. N-CNTs are coated with a polymer layer, as indicated by a comparison of the average diameter of N-CNTs before and after synthesis.

Based on the results of the contact potential difference, the work function of the electron was calculated (Table 1) [2]. It is shown that the work function of the nanostructure is larger than the work function of the CNTs. Furthermore, the work function of the PANI/N-CNT film is higher than that of the nanostructure.

Table 1. Work function, eV

N-CNT, [2]	PANI/N-CNT nanostructure	PANI/N-CNT film
4.5±0.12	4.67±0.26	4.79±0.18



(a) (b) (c)

Figure 1. (a) AFM and (b) EFM images of PANI/N-CNT nanostructure and (c) cross section line.

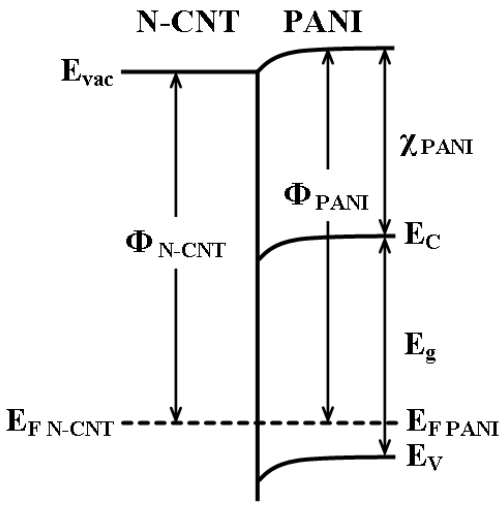


Figure 2. Energy diagram of PANI/N-CNT structure.

Figure 2 shows the energy diagram of the PANI/N-CNT structure. At the junction of the polymer/CNT, a space-charge region enriched in electrons arises in the polymer. PANI band bending down leads to a decrease in the work function. Therefore, with decreasing thickness of the polymer layer on CNT decreases the work function of PANI/N-CNT nanostructure. The work function of the bulk layer of PANI/N-CNT considerably exceeds the work function of nanostructure. This is due to the fact that the main contribution in the work function is provided by thick polymer layers on the CNTs, or unrelated polymer particles. Thus, the variation of both work function in the nanotubes and the thickness of the PANI layer on the CNTs make it possible to tuning the work function in the individual nanostructures of PANI/N-CNTs.

1. M. Eising, C.E. Cava, R.V. Salvatierra, et al., *Sensors and Actuators B: Chemical* **245**, 25 (2017).
2. N.A. Davletkildeev, D.V. Stetsko, V.V. Bolotov, et al., *Materials Letters* **161**, 534 (2015).